

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

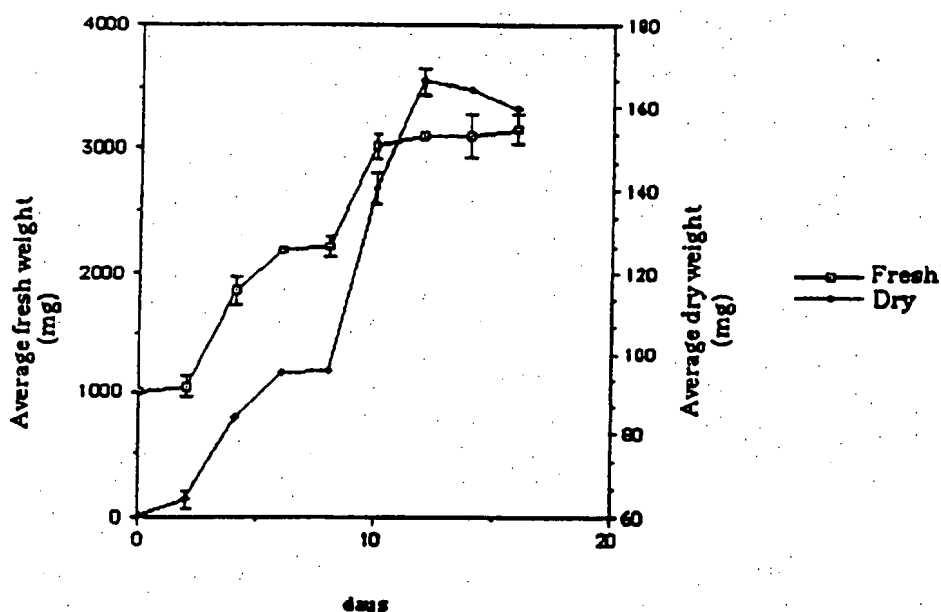


dup

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>5</sup> : C12P 17/02, C12N 5/00, 5/02 C12N 5/04, C12Q 1/00		A1	(11) International Publication Number: WO 93/17121 (43) International Publication Date: 2 September 1993 (02.09.93)
(21) International Application Number: PCT/US93/01576 (22) International Filing Date: 22 February 1993 (22.02.93) (30) Priority data: 07/839,144 20 February 1992 (20.02.92) US 07/874,344 24 April 1992 (24.04.92) US		(72) Inventors: BRINGI, Venkataraman ; 30 Meadowlark Drive (Lower), Ithaca, NY 14850 (US). KADKADE, Prakash, G. ; 45 Lambert Circle, Marlboro, MA 01752 (US). (74) Agents: BAKER, Hollie, L. et al.; Hale and Dorr, 1455 Pennsylvania Avenue, N.W., Washington, DC 20004 (US). (81) Designated States: AU, CA, JP, KR, NZ, PT, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report. With amended claims and statement.	
(71) Applicants: PHYTON CATALYTIC, INC. [US/US]; 175 Langmuir Lab, 95 Brown Road, Ithaca, NY 14850-1257 (US). PRINCE, Christopher, L. [CA/US]; 1102 E. Shore Drive, Ithaca, NY 14850 (US). SCHUBMEHL, Barry, F. [US/US]; 157 Waterwagon Road, Ithaca, NY 14850 (US). KANE, Eugene, J. [IE/US]; 1820 Slaterville Road, Ithaca, NY 14850 (US). ROACH, Braden [US/US]; 9205 Route 96, Interlaken, NY 14847 (US).			

(54) Title: ENHANCED PRODUCTION OF TAXOL AND TAXANES BY CELL CULTURES OF *TAXUS* SPECIES



(57) Abstract

This invention is directed to methods for the enhanced production and recovery of taxol and taxanes by cell cultures of *Taxus* species.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	MR	Mauritania
AU	Australia	GA	Gabon	MW	Malawi
BB	Barbados	GB	United Kingdom	NL	Netherlands
BE	Belgium	GN	Guinea	NO	Norway
BF	Burkina Faso	GR	Greece	NZ	New Zealand
BG	Bulgaria	HU	Hungary	PL	Poland
BJ	Benin	IE	Ireland	PT	Portugal
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SK	Slovak Republic
CI	Côte d'Ivoire	LI	Liechtenstein	SN	Senegal
CM	Cameroon	LK	Sri Lanka	SU	Soviet Union
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	MC	Monaco	TG	Togo
DE	Germany	MG	Madagascar	UA	Ukraine
DK	Denmark	ML	Mali	US	United States of America
ES	Spain	MN	Mongolia	VN	Viet Nam
FI	Finland				

## ENHANCED PRODUCTION OF TAXOL AND TAXANES BY CELL CULTURES OF TAXUS SPECIES

### BACKGROUND OF THE INVENTION

#### A. FIELD OF THE INVENTION

This invention is directed to methods for the enhanced production and recovery of taxol and taxanes by cell cultures of *Taxus* species.

#### B. RELATED ART

##### The Taxol Supply Problem and Possible Solutions

Taxol is a diterpenoid alkaloid originally isolated from the bark of the pacific yew, *Taxus brevifolia* (Wani et al. 1971).

Interest in taxol began when the National Cancer Institute (NCI), in a large-scale screening program, found that crude bark extracts exhibited anti-tumor activities. Since then, clinical trials have confirmed that taxol is extremely effective against refractory ovarian cancers, and against breast and other cancers. Taxol has been pronounced as a breakthrough in chemotherapy because of its fundamentally different mechanism of cytotoxicity, i.e., by inhibiting depolymerization of microtubules (see Rowinsky et al. 1990).

The most daunting variable in the taxol equation so far is supply. It takes three to six 100 year old Pacific yews to treat one patient because average yields of taxol are low - ca. 0.01% of dry bark and needles (Witherup et al. 1990). To produce the amount of taxol that is needed for treatment and testing would require the destruction of tens of thousands of yews. Thus far, all of the world's supply has come from harvesting these squat, slow growing conifers that populate the ancient forests of the Pacific Northwest. Unfortunately, the yew has been rendered nearly extinct by

logging. Conservationists are successfully opposing any large scale sacrificing of the tree, which grows in the ancient forest that are refuge to the endangered Northern spotted owl and other wildlife. As the number of Pacific yews dwindles, medical research is pinning its hopes for future taxol on new, alternative sources of supply. Three sources that have been considered are chemical synthesis, semi-synthesis and plant cell culture.

Taxol is a large, structurally complex chemical molecule that has thus far eluded total chemical synthesis. Therefore, large-scale synthesis from simple available chemicals is not likely to be a feasible option for the next few years.

A possible option for large-scale production is semi-synthesis, i.e., chemical attachment of a side chain to the agriculturally produced taxol precursor, baccatin. Significant progress has been made on the synthesis of the side chain (Denis et al. 1991). Methods have also been developed to couple the side chain to baccatin (Denis et al. 1990, U.S. Patent 4,924,011; Holton 1991, U.S. Patent 5,015,744). However, the agricultural supply of baccatin from needles of *Taxus* plantations is by no means trivial; and is currently being re-evaluated in light of the fact that earlier reports (Denis et al., 1988, 0.1% by weight) were more optimistic about baccatin content than recent ones (Witherup et al. 1990, 0.03 % dry weight). In summary, the ability of chemical synthesis and semi-synthesis to supply taxol for world-wide chemotherapeutic use is not assured. There are strong reasons for exploring and developing alternative means of production.

This invention is related to the development of a plant cell culture-based process for the supply of taxol and other taxanes.

#### **Tissue Cultures as a Source of Plant-Derived Chemicals**

The ability of plant cells to divide, grow, and produce secondary metabolites under a variety of different cultural regimes has been amply demonstrated by a number of groups. At present, two compounds, shikonin (a red dye and anti-

inflammatory) and ginsenoside (a tonic in oriental medicine) are produced by tissue-culture processes in Japan. Many other processes are reportedly close to commercialization, including vanillin, berberine and rosmarinic acid (see Payne et al. 1991).

The advantages of a plant cell culture process for taxol are many: (i) A cell culture process ensures a limitless, continuous and uniform supply of product, and is not subject to pests, disasters and seasonal fluctuations, (ii) cell cultures can be cultivated in large bioreactors, and can be induced to overproduce taxol by manipulating environmental conditions, (iii) cell cultures produce a simpler spectrum of compounds compared to bark or needles, considerably simplifying separation and purification, (iv) a cell culture process can adapt quickly to rapid changes in demand better than agriculture-based processes, (v) besides supplying taxol, a cell culture process could also produce taxane precursors such as baccatin that could be converted semi-synthetically into taxol and other active derivatives.

Since aseptic, large-scale, plant cell cultivation is inherently expensive, a cell culture process becomes commercially relevant only when these costs are offset by rapid cell growth and high metabolite productivity. Every plant species and target metabolite is different, and different approaches are necessary for every particular system. This invention focuses on creative and skilled approaches for obtaining rapidly growing and highly productive plant cell cultures for taxol and taxane production.

#### **Problems with Tissue Cultures of Woody Plants and Conifers**

A historical survey of the literature suggests that whereas herbaceous plants have been relatively easily manipulated in culture, cultures of woody plants and conifers have been achieved only with difficulty.

The growth of secondary metabolite producing gymnosperm- and conifer-cultures have been generally low. For example, Berlin and Witte (1988) found that

cultures of *Thuja occidentalis* increased their biomass by only ca. 30% in 18 days. Van Uden et al. (1990) reported a biomass increase of 20-50% in 21 days for suspensions of *Callitris drummondii*. Westgate et al. (1991) reported a doubling time of ca. 10 days for suspensions of the gymnosperm, *Cephalotaxus harringtonia*. As summarized by Bornman (1983), a tremendous amount of effort has been directed towards medium development for spruce suspensions (*Picea abies*). This collective work demonstrates that gymnosperm suspensions are indeed capable of rapid growth, but that no generalities can be applied, and that media formulations for different cell lines must be optimized independently.

A survey of secondary metabolite productivity among gymnosperm cultures also points to the difficulty of inducing rapid biosynthesis compared to herbaceous species. For example, cultures of *Cephalotaxus harringtonia* produced terpene alkaloids at a level of only 1% to 3% of that found in the parent plant (Delfel and Rothfus 1977). Even upon successful elicitation, Heinsteins (1985) was only able to approach the levels produced in the parent plant (ca. 0.04% dry weight total alkaloids). Van Uden et al (1990) were able to induce suspension cultures of the conifer *Callitris drummondii* to produce podophyllotoxin, but only at levels one tenth of that produced by the needles. The ability of *Thuja occidentalis* to produce significant levels of monoterpenes (10-20 mg/L) and the diterpenoid dehydroferruginol (2-8 mg/L) has been convincingly demonstrated by Berlin et al. (1988). However, these results were obtained with a slow-growing (30 % biomass increase in 18 days) and low cell density (5 to 7 grams dry weight per liter) culture.

#### **Cell Culture for Taxol Production: Previous Efforts**

The difficulties in achieving rapid growth and high productivity encountered in gymnosperm-suspensions have been reflected in the three reports so far on taxol production. Jaziri et al. (1991) recently initiated callus cultures of *Taxus baccata*,

but were unable to detect any taxol using their immunosorbent assay.

Wickremesinhe and Arteca (1991) reported the presence of 0.009% dry weight taxol in callus cultures of *Taxus media* (cv. hicksii), but details on the doubling times, cell densities, and the time-scale over which the reported taxol was produced, were not indicated.

U.S. Patent No. 5,019,504 (Christen et al. 1991) describes the production and recovery of taxane and taxane-like compounds by cell cultures of *Taxus brevifolia*. These workers reported taxol production at a level of 1 to 8 mg/L in a two- to four-week time frame. They also reported a cell mass increase of "5-10 times in 3-4 weeks", which corresponds to doubling times of ca. 7 to 12 days.

Increases in growth rates, taxol biosynthesis rates, and volumetric productivities are clearly necessary before a tissue culture process for taxol production can supply the projected annual demand of tens to hundreds of kilograms of taxol per year.

## SUMMARY OF THE INVENTION

The inventors have discovered that taxol and taxol-like compounds, or taxanes, can be produced in very high yield from all known *Taxus* species, i.e., *brevifolia*, *canadensis*, *cuspidata*, *baccata*, *globosa*, *floridana*, *wallichiana*, *media* and *chinensis*. In particular, the inventors found that the species, *Taxus chinensis*, is capable of rapid growth and of producing extremely high levels of taxol and taxanes within a short period of time.

Improving upon the invention described in Christen et al. (1991), the inventors herein have discovered that cell cultures from different *Taxus* species can be rapidly and efficiently initiated, and successfully grown on artificial nutrient media and that the same chemotherapeutically active taxane alkaloids are produced in the cell

culture as in the intact plant.

Further, by the methods of this invention it is possible to obtain taxol in a much shorter time frame than previously reported. With the species *Taxus chinensis*, the inventors have been able to manipulate cells to yield taxol in amounts far in excess of the amounts obtained from tissue cultures of the other *Taxus* species. Moreover, the growth rate of the *Taxus chinensis* cell cultures is significantly higher, 3 to 6 fold, than for *Taxus brevifolia* described in Christen et al. (1991).

The objects of this invention include the rapid and efficient initiation of cell cultures from various species of *Taxus*.

The objects of this invention include the formulation of special environmental conditions to foster rapid growth, high cell densities, and high cell viabilities. The growth characteristics reported in this study surpass previous results by a significant factor.

The objects of this invention include the ability to induce high and prolonged rates of taxol and taxane biosynthesis and secretion by: (a) careful manipulation of nutrient concentrations ('production medium formulation'), (b) use of light, (c) use of periodic medium exchange protocols, (d) use of elicitors.

The objects of this invention include the ability to manipulate the profile of taxanes produced by altering media formulations and environmental conditions. In particular, cells were coaxed to produce taxol as the predominant taxane product. In addition, the production of the by-product cephalomannine was suppressed, thereby providing an elegant biological solution to an expensive and important downstream separation and purification problem.

The objects of this invention include the ability to produce various taxanes other than taxol that might themselves show pharmacological activity, or may be modified and converted to compounds with pharmacological activity.

The objects of this invention include the ability to induce cell cultures of *Taxus chinensis* to produce taxol (0.32% dry weight) at levels far exceeding those produced



in wild plants (0.008 to 0.03% dry weight, Xu and Liu 1991).

## DESCRIPTION OF THE FIGURES

**Figure 1.** Biomass increase in a *Taxus chinensis* suspension culture line K-1 over a typical batch growth cycle in Medium A. Error bars represent the standard deviation measured from duplicate flasks.

**Figure 2.** Effect of medium exchange on days 9 & 12 on taxol (A) and total taxane (B) productivity in a 15-day experiment. The numbers in each box represent the time interval (days) over which the product was produced. The darkened portion of the intracellular boxes represents the taxol or total taxanes that were present in the cell inoculum at the start of the experiment. All treatments were performed in duplicate. *Taxus chinensis* suspension cell line K-1 was used with Medium A as elaborated in Table 2.

**Figure 3.** Spectral characteristics of a Standard Gro-Lux lamp (GTE Sylvania, Danvers, MA) used in Example 7.3.

**Figure 4.** Taxane production in *Taxus chinensis* cell suspension K-1. The portion of the chromatogram from 10 to 40 minutes is shown. Diode array scans of selected taxane peaks show a characteristic taxane UV absorption spectrum, with a peak at 227nm.

**Figure 5.** Taxol and taxane production after prolonged cultivation in Medium C by *Taxus chinensis* cell line K-1. The upper panel tabulates the data for the known and unknown taxanes, whereas the lower panel shows incremental taxol and taxane

production in the 25 to 42 day time period.

**Figure 6. MS/MS confirmation of taxol in cell culture supernatant.** Panel A shows the ion spray APCI mass spectrum of authentic taxol and panel B shows the daughter ion spectrum of the parent peak ( $m/z$  871 = taxol+ $\text{NH}_4^+$ ). Panel C represents the ion spray APCI spectrum from a crude cell culture extract and shows  $m/z$  854 and 871 characteristic of taxol. Panel D shows the corresponding daughter spectrum of  $m/z$  871 and provides unequivocal evidence for the presence of taxol in cell culture supernatant.

#### **DETAILED DESCRIPTION OF THE INVENTION**

Plants have long provided important sources of pharmaceuticals and specialty chemicals. These products have typically been obtained through extraction of the harvested plant materials or by chemical synthesis. Taxol has become one of the most important potential anticancer agents to recently emerge from the screening of natural products.

As used herein, the terms taxol and taxol-like compounds, or taxanes, are used interchangeably to describe a compound with a taxane ring. These compounds may themselves possess antineoplastic activity, or may be modified to yield bioactive compounds.

As used herein, the term "callus" is used to describe a mass of cultured plant cells that is structurally undifferentiated, and is cultivated on solidified medium. As used herein, the term "suspension culture" is used to describe structurally undifferentiated cells that are dispersed in a liquid nutrient medium. It is understood that suspension cultures comprise cells in various stages of aggregation. A range of aggregate sizes are encountered in the suspensions described in this invention, with sizes ranging from tens of microns in diameter (single cells or few-

aggregated cells) to aggregates many millimeters in diameter, consisting of many thousands of cells.

The plant material useful in this invention was obtained from all known *Taxus* species, i.e., *brevifolia*, *canadensis*, *cuspidata*, *baccata*, *globosa*, *floridana*, *wallichiana*, *media* and *chinensis*. In particular, the inventors have identified the species *Taxus chinensis* as capable of producing significant quantities of taxol and taxanes in a short period of culture time, with desired compounds being secreted continuously into the medium.

It has been found by the inventors that specific taxol content varies with plant species, and within plant species from tissue source and specific trees. Selecting a high yielding source for taxol production is an important first step towards providing sufficient quantities of taxol for therapeutic use.

#### Initiation of *Taxus* Cell Lines

*Taxus* plant material may be collected from all over North America as well as from other continents. The culture is initiated by selecting appropriate *Taxus* tissue for growth. Tissue from any part of the plant, including the bark, cambium, needles, stems, seeds, cones, and roots, may be selected for inducing callus. However, for optimum yield of taxol, needles and meristematic regions of plant parts are preferred. Most preferred are new growth needles (e.g., one to three months old), which can generally be identified by a lighter green color. The term "new growth" is broadly intended to mean plant needle production within that year's growing season.

To prevent contamination of the culture, the tissue should be surface-sterilized prior to introducing it to the culture medium. Any conventional sterilization technique, such as "Chlorox" (a trademark owned by the Chlorox Company for bleach) treatment would be effective. In addition, antimicrobial agents such as cefoxitin, benlate, cloxacillin, ampicillin, gentamycin sulfate, and phosphomycin may be used for surface sterilization of plant material.

### **Callus Growth**

Cultures will typically exhibit variability in growth morphology, productivity, product profiles, and other characteristics. Since individual cell lines vary in their preferences for growth medium constituents, many different growth media may be used for induction and proliferation of the callus.

The appropriate medium composition varies with the species being cultured. The preferred media for the different species are listed in Table 3. For example, although others may be used, the two preferred growth nutrient media for *Taxus chinensis* are A & D. These media preferably contain the ingredients listed in Table 2. For example, when A medium is used, growth hormones or regulators incorporated into the medium in an amount between 1 ppb to 10 ppm, and preferably at 2 ppb to 1 ppm. When medium D is used, the growth hormones or regulators are incorporated at levels ranging from 1 ppb to 10 ppm, and preferably at 2 ppb to 2 ppm. The amounts of other medium ingredients can be incorporated at levels ranging from 1/10th concentration to three times the concentrations indicated in Table 2, but are preferably incorporated at the levels shown in Table 2.

### **Suspension Growth**

*Taxus* suspension cultures are capable of rapid growth rates and high cell densities like other plant cell cultures. However, optimal conditions vary from one cell line to another, and accordingly, methods leading towards rapid optimization for any given cell line must be considered.

The initial cultures of various *Taxus* species are subcultured by transfer into the media listed in Table 3, containing macro and micronutrients, organic salts and growth hormones. The amounts are generally with the following ranges: starting with 1/10th concentration to three times the concentration of each medium

ingredient shown in Table 2. The preferred levels are those listed in Table 2.

The liquid cultures are exposed to air and preferably shaken or otherwise gently moved to introduce air into the medium, or air may be introduced through tubing into the culture vessels. The cultures are maintained under appropriate growth conditions at a temperature between 20° to 26°C. The pH may be from about 3 to 7 and preferably between 4 to 6. The culture may be grown under light conditions ranging from total darkness to total light (narrow band and/or broad spectrum) for various periods of time. Because total taxol production is highest in cultures exposed to light, this is preferred. Typical light intensity conditions range between about 100 to about 3000 foot candle power.

The suspension cultures are maintained for 1 to 8 weeks from the time of subculturing, after which culture growth declines. The cultures are harvested by removal of the growth medium, as by filtration. The harvested culture is weighed and dried, as by lyophilization, ground to a fine powder, and the taxol may be extracted by use of conventional solvent extraction techniques.

Doubling times have been measured by monitoring time-dependent biomass increase, as well as by simply monitoring the growth index during routine subculture. Maximum dry weight densities of 15-24 grams per liter have been achieved. The growth characteristics of various *Taxus* species suspensions are elaborated in Example 4.

#### **Analytical Methods**

Methods for the extraction and recovery of taxol and taxanes from cells and the medium follow conventional techniques and are described in detail in Example 5. The immuno-assay (ELISA) technique largely followed the protocols supplied by Hawaii Biotechnology in the commercially available kit. High performance liquid chromatography methods were slightly modified from existing protocols as elaborated in Example 5. Under the conditions used in this invention, clear

resolution of taxane peaks was achieved, resulting in accurate detection and quantitation. Because of the possibility of co-eluting non-taxane components, the spectral purity of every putative taxane peak was checked by diode array before integration of peak areas. Retention times of taxane standards are listed in Example 5, and a sample chromatogram is included in Figure 4.

### **Production Medium Conditions**

As used herein, the term "nutrient medium" is used to describe a medium that is suitable for the cultivation of plant cell callus and suspension cultures. The term "nutrient medium" is general and encompasses both "growth medium" and "production medium". The term "growth medium" is used to describe an nutrient medium that favors rapid growth of cultured cells. The term "production medium" refers to an nutrient medium that favors taxol and taxane biosynthesis in cultured cells. It is understood that growth can occur in a production medium, and that production can take place in a growth medium; and that both optimum growth and production can take place in a single nutrient medium.

Certain classes of additives in the nutrient medium are referred to by special names in this invention, and are defined here. As used herein, the term "anti-browning agents" refer to components that are added to the nutrient medium to prevent the formation of pigments during cell cultivation. These pigments include phenolics and related compounds that are generally observed to have a deleterious effect on cell growth, viability, and product formation. As used herein, the term "biosynthetic precursors" are used to describe compounds added to the nutrient medium that are metabolized and incorporated by the cells into taxol and taxanes. As used herein, the term "metabolic inhibitors" are used to describe compounds added to the nutrient medium that interfere with specific biosynthetic pathways. For example, a metabolic inhibitor may be used to enhance taxol biosynthesis by blocking a different pathway that competes with taxol for an early biosynthetic precursor. As

used herein, the term stimulator or activator is used to describe compounds added to the nutrient medium that stimulate or activate specific biosynthetic pathways, for example those leading to taxol biosynthesis. It is understood that the mechanism of action of the additives described herein may not be completely understood.

If secondary metabolite formation in a suspension culture takes place concurrently with growth, the metabolite is termed growth-associated, and a single medium formulation may be sufficient to achieve good growth and high level production. In many other systems, it has been found that rapid growth and high product formation do not take place concurrently. In such cases, growth and production phases are separated and a medium for each phase is developed independently (reviewed in Payne et al. 1991). In the case of taxol and taxane production in *Taxus chinensis*, growth and rapid product formation have been separated, and independent media have been developed for each. However, it is understood that a single growth/production medium may be formulated for this culture. The production media developed here not only increase total taxol and taxane formation, but also direct cellular biosynthesis towards taxol production. In addition, production of interfering by-products such as cephalomannine is minimal compared to bark tissue. The production media developed here also promote prolonged cell viability and biosynthesis, and in addition, cause significant levels of product to be secreted into the extracellular medium. These characteristics are extremely important in the operation of an efficient commercial scale process for taxol production.

Although others may be used, the preferred production media for the various species are listed in Table 5. For example, although others may be used, the preferred production media for *Taxus chinensis* are B & C. These media preferably contain the ingredients listed in Table 2. These media preferably contain major and minor inorganic salts, organics and growth hormones or growth regulators. The amounts are generally with the following ranges starting with the 1/10th to three

times the concentration of each medium ingredient indicated in Table 2. However, the preferred levels are those listed in Table 2.

Where medium B is used, the growth regulators are incorporated into the medium in an amount between 0.1 ppm to 20 ppm, and preferably between 1 ppm to 10 ppm. When Medium C is used, the growth regulators are incorporated preferably at levels ranging from 0.1 ppm to 5 ppm.

It is understood that modifications may be made in this medium such as substitution of other conventional salt compositions (such as organics, vitamins, amino acids, precursors, activators and inhibitors), addition or deletion of various components, growth regulators or alteration of proportions.

In addition to non-volatile dissolved nutrients, gaseous components, primarily oxygen, carbon dioxide, and ethylene (a plant hormone), play critical roles in growth and product formation. Two parameters are important. The dissolved gas concentrations favoring growth and taxol formation are obviously important since they dictate reactor operating conditions. In addition, the rates of consumption or production need to be incorporated into reactor design, so that the optimum specified concentrations can be maintained.

Besides its importance in respiration, oxygen can also dramatically affect the rate of secondary biosynthesis. A high saturation constant for an oxygen-requiring step on a secondary biosynthetic pathway may require cells to be subjected to high oxygen levels in the reactor. The importance of CO<sub>2</sub> supplementation in maintaining high growth rates has been documented. Ethylene, a plant hormone, plays pleiotropic roles in all aspects of plant growth and development, including secondary metabolism (e.g., see Payne et al., 1991).

### **Elicitors**

In order to improve the yield of taxol and other related taxanes in cell cultures, the inventors have undertaken a number of approaches. One of the approaches that



has been used to enhance productivity is the use of so-called elicitors. As used herein, the term elicitors is used for compounds of biological and non-biological origin that cause an increase in secondary metabolite production when applied to plants or plant-cell cultures (Eilert 1987; Ebel 1984; and Darvill et al. 1984). Many different compounds can act as elicitors, depending upon their nature of origin and their mode of action with cell metabolism. In these studies, the inventors have used two major kinds of elicitors: 1) Biotic elicitors which usually comprise cell wall extracts or filtrates from a selected group of fungi, bacteria and yeasts, and also their purified fractions. 2) Abiotic elicitors which have included chemical stress agents as well as some compounds of biological origin (see elicitors listed in Table 1).

Christen et al.(1991) report the use of fungal elicitors and selected compounds for production of taxol by suspensions of *Taxus brevifolia*; however, the increases in the level of taxol accumulation due to elicitor treatments have not been specified.

In general, both kinds of elicitors were effective, although the extent to which elicitation (taxane accumulation in cell cultures as well as their secretion into the medium) occurred differed from elicitor to elicitor and from species to species. The highest production increase was attained with chitosan glutamate, lichenan, ferulic acid and benzoic acid. Chitosan and lichenan are complex polysaccharides derived from microbial cell walls. Chitosan when used alone is insoluble in medium, and is toxic and causes permanent cell damage. Chitosan glutamate, on the other hand, is readily soluble in medium and does not affect cell viability. Ferulic and benzoic acids are synthesized chemicals of biological origin, and are generally used as anti-oxidants in biological systems.

Elicitors interact with dissolved gases in many ways. Oxygen requirements may change upon elicitation. Increases in respiration rates as a wound response is commonly observed in plant cell cultures. Importantly, elicitors may mediate their action via ethylene. In such cases, it may be desirable to substitute a microbial

elicitor preparation with ethylene, and perhaps prevent toxicity associated with other microbial components in the elicitor preparation.

Elicitors and metabolic stress agents may be utilized according to this invention to maximize taxol production and secretion in tissue culture by assessing elicitor specificity and concentration, timing, and duration, as a function of culture age and media composition.

#### **Rapid Medium Exchange for Productivity Enhancement**

As documented in Example 7.3., the removal of spent medium and replenishment of fresh medium every 3 days contributed to significant enhancement of total taxane and taxol production, as well as to an increase in the amounts of extracellular product.

The stimulatory effects of medium exchange may have been due to removal of product *in situ*, which would prevent feedback inhibition and product degradation. Such positive effects of *in situ* product removal on secondary metabolite production and secretion in suspension cultures have been documented by, among others, Robins and Rhodes (1986) and Asada and Shuler (1989). The periodic removal of spent medium incorporates the above advantages, and additionally, may serve to de-repress secondary biosynthesis by removing other, non-taxane, inhibitory components (such as phenolic compounds) from the medium.

The replenishment of fresh medium to cells undergoing active biosynthesis may also enhance production by providing essential nutrients that have been depleted. For example, Miyasaka et al. (1986) were able to stimulate stationary phase cells of *Salvia miltiorhiza* to produce the diterpene metabolites, cryptotanshinone and ferruginol simply by adding sucrose to the medium. Presumably, biosynthesis had ceased due to carbon limitation in the stationary phase. The periodic-medium-exchange protocol used in the present work could have been beneficial as a result of any of the above factors.

It is understood that the amount of medium exchanged, the frequency of exchange, and the composition of the medium being replenished may be varied.

The ability to stimulate biosynthesis and secretion by periodic medium exchange has important implications for the design and operation of an efficient commercial process in the continuous, semi-continuous or fed-batch mode.

### **Light**

For higher plants, light is a potent factor in secondary metabolism both in intact plant as well as in cell cultures. Both the intensity and wavelength of light are important (Seibert and Kadkade 1980). For example, flavanoid and anthocyanin biosynthesis are usually favored by high intensity continuous light, while dark-cultivated cultures may be preferable for other metabolites. Increase in greening or photosynthetic capacity of cultured cells may also increase product formation or product spectrum. The inventors' studies involved the use of broad-band and well as specific narrow-band light sources. As shown in Example 7.8., light exposure can bring about increased taxol accumulation as well as secretion into the medium. The stimulatory effect of light on taxol production suggests the existence of unique control mechanisms for biosynthesis of taxanes. The nature of the photoreceptor and biochemical characteristics of light-induced stimulation are not yet clear.

### **Modes of Process Operation**

The operating mode for a plant cell culture process refers to the way that nutrients, cells and products are added or removed with respect to time (Payne et al. 1991). When all the nutrients are supplied initially, and the culture contents comprising cells and product are harvested at the end of the culture period, the operating mode is termed a "one-stage batch process". When a batch process is divided into two sequential phases, a growth and a production phase, with the medium being exchanged in between the two phases, the operating mode is termed a

"two-stage batch process".

In a "fed-batch" operation, particular medium additives and nutrients are supplied either periodically or continuously through the course of a one-stage or a two-stage batch culture.

When a substantial portion, but not all, of the contents of a batch culture is harvested, with addition of fresh medium for continued cell growth and production, the process resembles a "repeated draw and fill" operation, and is termed a "semi-continuous process".

When fresh medium is continuously supplied, and effluent medium is continuously removed, the process is termed "continuous". If cells are retained within the reactor, the process is termed a "perfusion mode". If cells are continuously removed with the effluent medium, the continuous process is termed a "chemostat".

It is understood that these various modes of process operation are compatible with the taxol-production system described herein.

## **EXAMPLES**

The following examples further describe the Materials and Methods used in carrying out the invention. The examples are intended to be illustrative and are not intended to limit the invention in any manner.

### **Example 1:**

#### **Callus Initiation**

Samples of *Taxus* plant material were collected from a number of wild and cultivated plants. Samples were processed upon arrival at the laboratory or stored at 4°C until they could be used.

The material was first washed in dilute soap solution, rinsed in water, and the

surface sterilized in a Chlorox solution (1% hypochlorite, pH 7) for 10 minutes. Under sterile conditions the material was then rinsed 3 times with sterile water. Needles were then cut in a 1% polyvinylpyrrolidone (PVP) solution with 100 mg/l ascorbic acid. Needles were placed with the cut end in Medium E (see Table 2). Thirty to forty explants were cultured per plate of medium. Plates containing explants were incubated at  $24\pm 1^\circ\text{C}$  in the dark. Plates were monitored daily for the appearance of contaminating micro-organisms, and where they were present, uncontaminated needles were removed and placed in a fresh plate of Medium E. Substantial callus formation was observed and the callus was separated from the explant by 20 days and placed on the various callus proliferation media listed in Table 3. For example, calli of *Taxus chinensis* were transferred to Medium D (see Table 2). This initiation procedure was very efficient, resulting in low contamination rate and high frequency of callus induction of over 90 % of explants initiated. The same procedure was successfully used to initiate cultures of *Taxus brevifolia*, *Taxus canadensis*, *Taxus cuspidata*, *Taxus baccata*, *Taxus globosa*, *Taxus floridana*, *Taxus wallichiana*, *Taxus media*, and *Taxus chinensis*.

### **Example 2:**

#### **Callus Proliferation**

Once calli were removed from the explant, they are cultivated at  $24\pm 1^\circ\text{C}$  in the dark. Healthy parts of the callus were transferred to fresh medium every 10 days, and this frequency of transfer was found to be extremely important for prevention of browning and for prolonged callus maintenance. The preferred growth and maintenance media for calli of various species are summarized in Table 3.

### **Example 3:**

#### **Suspension Initiation**

1 g fresh weight of callus material was aseptically inoculated into a 125 ml

Erlenmeyer flask containing 25 ml of liquid medium appropriate to each species (see Table 3). For example, Medium D was used for *Taxus chinensis*. The flask was covered with a silicone foam cap (Bellco, NJ) and placed on a gyratory shaker at 120 rpm at  $24 \pm 1^\circ\text{C}$  in darkness. Suspension cultures were formed in approximately 3 to 10 days. Initially, medium was exchanged by suction filtering the flask contents through a buchner funnel containing a miracloth filter (Calbiochem), and resuspending all the biomass in fresh medium. Upon cell growth, 1-2 g (fresh weight) of cells were generally transferred into a new 125 ml flask containing 25 mL of fresh medium and were thereafter subcultured weekly.

#### **Example 4:**

##### **Growth of Suspended Cells**

The typical growth rates and cell densities achieved in suspension cultures of representative species are listed in Table 4.

As a detailed example, the increase in biomass (fresh and dry weight) with time for *Taxus chinensis* line K-1 is shown in Figure 1. The maximum growth rate was measured by taking the slope at points of most rapid biomass increase on the growth curves. Cell cultures of *Taxus chinensis* grew at a maximum doubling time of 2.5 days. This growth rate is significantly higher than that reported previously for *Taxus* species suspension cultures. For example, Christen et al. (1991) reported a 5- to 10-fold increase in biomass after 3 to 4 weeks of culture, which translates to an average doubling time for *Taxus brevifolia* suspensions of 7 to 12 days.

The ability to cultivate cells at a high density is important in maximizing the volumetric productivity of a cell culture process. Whereas cultures of *Taxus brevifolia* reached a cell density of less than 1 g dry weight per liter (calculated from data presented in Christen et al. (1991)), suspensions of *Taxus chinensis* were able to reach densities of up to 8 to 20 g dry weight per liter after 18 days of growth. The

viability of cells was determined by staining cells with a 0.05% solution of fluorescein diacetate in acetone (Widholm, 1972), and by counting the number of green fluorescing cells upon excitation with blue light in an inverted fluorescence microscope (Olympus IMT-2, Japan). Cell viability was higher than 90% throughout the growth phase.

The ability to cultivate cells under rapid growth conditions to high cell densities while retaining high viability is an important pre-requisite to the economic operation of a plant cell culture process for producing taxol and taxol-like compounds.

### **Example 5:**

#### **Analysis of Taxol and Taxanes**

##### **5.1. ELISA Methods**

ELISA analysis for taxol (Hawaii Biotech) was used for large scale screening of cell lines. This method provides high sensitivity (0.1 ng/mL), however, because a polyclonal antibody is used, cross-reactivity with other taxanes is observed. Preparative (analytical scale) HPLC with fraction collection showed cross-reactivity with 10-deacetyltaxol, 7 xylosyl-10-deacetyltaxol, cephalomannine, 10-deacetyl-7-epitaxol, 7 epitaxol, as well as other unidentified taxanes. Despite such cross-reactivity this method was found to be extremely useful for detection of taxane production and allowed large numbers of cell lines to be screened quickly. Cell extracts showing significant production of taxanes were then analyzed in detail using the HPLC procedure outlined below.

##### **5.2. Extraction of Taxol and Related Taxanes**

Extraction of taxanes from supernatants were performed by two methods, depending on the concentrations present in the media. When sufficient amounts of

taxanes are present in liquid media, samples were prepared very rapidly and efficiently. Media (2 mL) were dried completely (in vacuo) and a measured amount of methanol (0.5-2.0 mL) was added. This mixture was agitated ultrasonically until complete dissolution or dispersion of the sample was accomplished. Solids were removed by centrifugation prior to HPLC analysis. Quantitative recoveries have been obtained at 1 mg/L levels with detection levels well below 0.1 mg/L.

When concentration of taxanes in the culture supernatants were low, the medium was extracted three times with an equal volume of a mixture of methylene chloride and isopropyl alcohol (IPA) (9:1 by vol.). The organic layer was reduced to dryness and reconstituted in a measured volume of methanol (50-250 mL). Multiple extraction typically recovered 90-95% of the taxol, cephalomannine, and baccatin III at 0.6 mg/L levels.

Cell materials were extracted by freezing freshly harvested cells (-5° C), followed by vacuum drying, and methanol soxhleting for 50 cycles. 70 to 80% of the taxanes were generally recovered with 10-15% measurable decomposition. The extraction of solid media and callus was accomplished identically to that of cells, however, methylene chloride/IPA vs. water partitioning of the final methanol extract was always performed.

### 5.3. High Performance Liquid Chromatography Methods

Analytical high performance liquid chromatography (HPLC) was performed on a high-carbon loaded diphenyl column (Supelco, 5 mM, 4.6 mm X 25 cm) with an LDC Analytical binary gradient high pressure mixing system consisting of CM3500/CM3200 pumps, a CM4100 variable volume autosampler and an SM5000 photo diode array detector interfaced to a Total Peripherals 486 personal computer. Column temperature was regulated at 35° C with an Eldex CH150 column oven. Quantitative HPLC analysis of taxanes was accomplished using a binary gradient elution scheme as follows:



<u>Time</u>	<u>% Eluant A</u>	<u>% Eluant B</u>	<u>Flow</u>
0	75	25	1 mL/min
40	35	65	"
42	25	75	"
47	25	75	"
50	75	25	"

Eluant A = 0.015M  $\text{KH}_2\text{PO}_4$  brought to pH 3.5 with trifluoroacetic acid  
 Eluant B = acetonitrile

The chromatographic methods used resemble several published methods (Witherup et al. 1989) with the exceptions that a phosphate buffer containing trifluoroacetic acid has been used and that a longer gradient is employed. These differences significantly improve the resolution of taxol and other taxanes from the mixture. The relative retention times observed for taxanes are shown below. Taxol elutes between 31 and 33 minutes depending on the column and hardware used.

<u>Compound</u>	<u>Relative Retention Time</u>
10-deacetylbaecatin III	0.38
baecatin III	0.56
7-xylosyl-10-deacetyltaxol C	0.80
10-deacetyltaxol C	0.87
cephalomannine	0.94
10-deacetyl-7-epitaxol C	0.98
taxol C	1.00
7-epitaxol	1.12

The retention times of taxol, cephalomannine and baecatin III were determined using authentic samples obtained from the National Cancer Institute. The retention times of the other taxanes listed above were compared to analytical standards provided by Hauser Chemical (Boulder CO). Identification of known taxanes was based on retention time and ultraviolet spectral comparisons. Quantitation of taxol, cephalomannine and baecatin III was based on response factors determined from authentic materials. Quantitation of 10-deacetylbaecatin III was performed using the response factor determined for baecatin III. Quantitation of the remaining taxol derivatives was based conservatively on the response factor

measured for taxol.

Each of the standards (10 mL) was typically injected (initially then after 3 or 4 samples) and areas for each of the three components were integrated. Response factors for each of the components was obtained by linear least-squares analysis of the data. 10 mL of each sample was injected and the amount per injection was calculated based on the standard data regression. These results were converted to amount per liter or percent dry weight. Figure 4 illustrates a typical chromatogram of a supernatant sample.

#### 5.4. MS/MS Confirmation of Taxol

The identity of taxol in cell culture supernatant has been confirmed using an MS/MS method (as shown in Figure 6) which couples flow injection with ion spray atmospheric pressure chemical ionization. Details of the procedures used for acquiring the data presented in Figure 6 were as follows: Mass Spectrometer: Sciex API 3 triple quadrupole with an atmospheric pressure ionization source. Nitrogen was used as the curtain gas and argon was used as the collision gas for the CID spectra. Interface: Ion Spray interface producing ions by Ion Evaporation Ionization (Electrospray). Zero air was used as the nebulizer gas. LC Pump: ABI 140B dual syringe pump operating at 5  $\mu$ L/minute. Solvents: 50/50 acetonitrile/H<sub>2</sub>O 2mM NH<sub>4</sub>OAc + 0.1% formic acid. Injection Volume: 5  $\mu$ L, all spectra taken by flow injection analysis. This method provided unequivocal confirmation for the presence of taxol in cell culture samples, and also provided quantitation with excellent agreement to HPLC results.

#### Example 6:

##### **Taxol production by various species**

The taxol produced by cell cultures of various *Taxus* species is summarized in Table 5. Callus was cultivated for 20 days in the dark on the indicated solidified

medium for each species. The cells and medium were dried and methanol-extracted together, and assayed by either ELISA or HPLC as indicated. The results obtained with *Taxus chinensis* cultures are elaborated further in Examples 7 and 8.

### **Example 7:**

#### **7.1 Production in growth medium**

The production of taxol and related taxanes commenced within the first 2 days of transfer into growth Medium A. The maximum taxol observed was on day 15, at 8.81 µg/flask, which corresponds to 0.44 mg/liter taxol. Of this, 46.1% was present in the extracellular medium. On day 15, the total taxane concentration was 72.87 µg/flask, or 3.6 mg/liter, of which 58.6% was present in the extracellular medium. The viability of cells was always greater than 90% as measured by fluorescence staining (Example 4), suggesting that the presence of extracellular taxol and taxanes was due to secretion rather than due to cell lysis. The ability of cells to secrete taxol and taxanes will be an important aspect of continuous operation.

#### **7.2 Medium exchange for productivity enhancement**

Significant improvements in taxol and total taxane productivity were obtained by aseptically suctioning off growth Medium A on day 9, replacing with fresh medium and repeating the procedure on day 12. The experiment was terminated on day 15, and the results are shown in Figure 2. The important increases in productivity due to medium exchange are summarized in Table 6. The total amounts of taxol and taxanes produced were ca. 4.6-fold higher with medium exchange compared to controls without treatment. Importantly, ca. 4.9-fold higher taxol, and ca. 5.9-fold higher total taxanes were recovered in the extracellular medium compared to controls without medium exchange treatment.

The ability to markedly enhance taxol and total taxane productivities, and

moreover, to cause extracellular product accumulation is important for operation of an efficient, continuous process with biomass reuse and simplified downstream purification.

### **7.3. Effect of Light on taxane production in growth medium**

Light is known to play an important role not only in photosynthesis, but also in various aspects of secondary metabolism in plant cell cultures (Seibert and Kadkade 1980). Whereas the experiments described in Examples 4, 7.1, and 7.2 were conducted in darkness, the response of *Taxus chinensis* cultures to light is described here.

One gram fresh weight of 7-day old cells of *Taxus chinensis* line K-1 were inoculated in 25 ml of growth Medium A (see Table 2) in 125 ml Erlenmeyer flasks and incubated at  $24 \pm 1$  °C on a gyratory shaker at 120 rpm. Duplicate flasks were placed in the dark and under a Standard GroLux lamp at a distance of 3 feet. Spectral characteristics of the lamp are shown in Figure 3. Results are shown in Table 7.

Exposure of cultures to light did not affect total taxane levels or the extent of extracellular accumulation. However, taxane profiles were significantly altered in the two treatments. For example, cells cultivated in the light produced 2.8 fold higher taxol than did cells in the dark. The proportion of extracellular taxol was also significantly higher than in the dark treatment (76% vs 56%). The use of light treatment, especially of specific spectral quality, would thus be extremely useful in a cell culture process for taxol production.

### **Example 8:**

#### **Elicitors**

The term elicitors is used for compounds of biological (or biotic) and non-biological (or abiotic) origin that cause an increase in secondary metabolism when added to plant cell cultures.

While a number of elicitors have been found useful, a representative illustrative example is described here in detail, namely, the use of chitosan glutamate. While chitosan has been previously tried as an elicitor in some plant cell culture systems, the accompanying toxic reactions such as browning and loss of viability have made its use impractical (Beaumont and Knorr 1987). Indeed such toxic side reactions are a common drawback of many elicitors reported in the literature. The use of chemically modified chitosans such as chitosan glutamate to specifically induce taxol and taxane biosynthesis while circumventing toxic side-effects is a novel approach.

Suspensions of *Taxus chinensis* line K-1 grown in Medium D for 7 to 8 days were suction filtered aseptically using a sterile Buchner funnel fitted with a miracloth (Calbiochem) filter. 2 g fresh weight cells were aseptically transferred to 25 ml of medium C (see Table 2) in a 125-mL Erlenmeyer flask. A solution of 0.05% chitosan glutamate was prepared freshly and filter-sterilized through a 0.22 micron cartridge filter. 825  $\mu$ L of this solution was added to the flask at the start of the experiment, corresponding to a level of 165 mg elicitor per gram dry weight cells. The flasks were incubated at  $24 \pm 1^\circ$  C on a gyratory shaker at 110 rpm in the dark. The flasks were destructively sampled on day 15, and observations on growth, color of the cells and medium and cell viability were recorded. Freeze-dried samples were methanol-extracted for taxol and taxanes as described in Example 5, and were analyzed by HPLC. The results of this experiment are shown in Table 8.

Elicitor treatment resulted in a modest improvement in the per-cell total taxane production (0.53% vs. 0.42% dry weight taxanes) over non-treated controls. The non-toxic nature of the elicitor is evident from the high viabilities (75-80%) observed in both treatments. In fact, an increased dry weight in elicitor treatment compared to controls has been reproducibly observed (14.2 g/l vs. 10.1 g/l dry weight). The higher cell densities resulted in an 1.8-fold greater titer of total taxanes in the elicitor treatment, i.e., 75.8 mg/L versus 42.4 mg/L for the control.

The elicitor treatment resulted in increased taxol biosynthesis, both on a per-cell basis (0.098% vs. 0.054% dry weight taxol, a 1.8-fold increase) and in a titer comparison (13.9 mg/L versus 5.4 mg/L, a 2.6-fold increase). The extent of secretion was higher for the elicitor treatment compared to the control (85% versus 72% extracellular product).

The elicitor treatment described herein results in increased taxol production, a more favorable product profile, enhanced product secretion and retention of high cell viability. These production characteristics represent a significant improvement for a cell culture process for taxol production.

### **Example 9:**

#### **Production medium development**

In an effort to increase taxol productivities over the levels described in example 6, nutrient levels were manipulated to formulate special 'production media'. 7 to 8 day old suspensions of *Taxus chinensis* line K-1 grown in Medium D were suction filtered aseptically using a sterile Buchner funnel fitted with a miracloth (Calbiochem) filter. 500 mg fresh weight cells were aseptically transferred to 5 ml of production Media B and C (see Table 2). The vessels were incubated for varying time periods of 18, 25, and 42 days at  $24 \pm 1^\circ \text{C}$  on a gyratory shaker at 110 rpm in the dark. Treatments were destructively sampled, and observations on growth, color of the cells and medium, and cell viability were recorded. Freeze-dried samples were methanol-extracted for taxol and taxanes as described in Example 5, and were analyzed by HPLC.

#### **9.1. Results of 18-day Cultivation**

*Taxus chinensis* cell cultures responded to the altered medium compositions by producing significant levels of taxanes and taxol. These data are summarized in Table 9, and a sample chromatogram is shown in Figure 4. In medium B, 99.8

mg/liter of total taxanes were produced, with 24.1 mg/liter of pure taxol. In Medium C, 110 mg/liter of total taxanes were produced, with 21.8 mg/liter of taxol. On a dry weight basis, cells produced 0.18% dry weight taxol on medium B, and 0.065 % dry weight taxol on medium C.

## 9.2. Prolonged Cultivation

Taxol and taxane production after prolonged cultivation of *Taxus chinensis* cells (line K-1) for 25 and 42 days was studied in medium C, the results for which are summarized in Figure 5. The following significant observations can be summarized:

- (i) *Taxus* suspension cultures are capable of producing significant levels of taxol and other taxanes. Highest accumulation occurred at 42 days, with 0.32% dry weight taxol, and 0.62% dry weight total taxanes; corresponding to titers of 153 mg/L taxol and 295 mg/L total taxanes based on final medium volume. The analysis of this sample by tandem mass spectrometry confirmed the presence of taxol as shown in Figure 6. Quantitation by MS/MS showed excellent agreement with HPLC.
- (ii) The rate of taxol biosynthesis between days 25 and 42 was at ca. 7.6 mg taxol per liter per day assuming linear production in the 17-day period. This rate is significantly higher than the rate of production in the first 25 days. The rate of total taxane biosynthesis between days 25 and 42 was 12.3 mg per liter per day.
- (iii) Production medium formulations can induce up to 45-fold increases in specific taxol content compared to rapid growth conditions such as those described in Example 7.
- (iv) The product spectrum can be manipulated so as to funnel biosynthesis towards the desired end-product taxol, while minimizing production of undesirable taxanes. For example, on day 25, taxol constituted 28% of the total taxanes and on day 42, taxol constituted 52% of the total taxanes in contrast to growth medium (see Example 7.1),

in which taxol constituted only 12.2% of the total taxanes. This ability to manipulate product profiles will have important repercussions for downstream purification and for product purity-related regulatory issues. For example, the ability to suppress production of the taxane by-product, cephalomannine could greatly simplify downstream purification compared to purification of taxol from bark tissue.

(v) *Taxus* cell cultures have been induced to secrete significant amounts of taxol (87% on day 42) and other taxanes. That the presence of extracellular taxol and taxanes is due to secretion rather than due to cell lysis is corroborated by several independent observations: (a) continued biosynthesis occurred between days 25 and 42, suggesting that cells were viable and active. Independent observations have shown that >70% viability have been observed after 18 days in production medium, (b) different percentages of different taxanes were secreted. If cells had lysed, the percentage in the medium might have been expected to be similar for the different taxanes.

(vi) The ability of this *Taxus* cell line to thrive and produce taxol at high rates in an extracellular environment so rich in product is particularly worth noting.

(vii) The *Taxus* cell line with which these results were obtained is also capable of rapid growth to high cell densities, and expressed the reported productivities after 20 generations under rapid-growth conditions, attesting to its stability and commercial potential.

The levels of taxol and taxanes produced by cell lines of *Taxus chinensis* under the conditions described herein are higher than previously reported results by a factor of 35- to 150-fold. For example, Christen et al. (1991) reported the production of 1 to 3 mg/liter of taxol by suspension cultures of *Taxus brevifolia* after 2 to 4 weeks of cultivation. Wickeramesinhe and Arteca (1991) reported the production of taxol at 0.009% dry weight in cell cultures of *Taxus media*.

In summary, our data show that with careful initiation and selection of



*Taxus chinensis* cultures, and with specially formulated growth medium conditions, cells can be induced to grow rapidly to high cell densities. When these cells are transferred to production medium conditions, cells are able to biosynthesize and secrete significant levels of taxol and other taxanes for prolonged periods while maintaining high viabilities. The incorporation of periodic medium exchange, light and elicitors with production medium results in further synergistic productivity enhancements. These properties are critical prerequisites for an efficient commercial process for taxol and taxane production using tissue culture technology.

## REFERENCES

- M. Asada and M.L. Shuler. 1989. Stimulation of Ajmalicine Production and Excretion from *Catharanthus roseus*: Effects of adsorption *in situ*, Elicitors, and Alginate Immobilization. *Appl. Microbiol. Biotechnol.*, 30, 475-481.
- M. D. Beaumont and D. Knorr. 1987. Effects of immobilizing agents and Procedures on Viability of Cultured Celery (*Apium graveolens*) Cells. *Biotechnol. Lett.* 9, 377-382.
- J. Berlin and L. Witte. 1988. Formation of Mono- and Diterpenoids by Cultured Cells of *Thuja Occidentalis*. *Phytochemistry*. 27, 127-132.
- C.H. Bornman. 1983. Possibilities and Constraints in the Regeneration of Trees from Cotyledonary needles of *Picea abies* in vitro. *Physiol. Plant.* 57, 5-16.
- A.A. Christen, D.M. Gibson and J. Bland. 1991. Production of Taxol or Taxol-Like Compounds in Cell Culture. U.S. Patent 5019504.
- A.G. Darvill and P. Albersheim. 1984. Phytoalexins and their Elicitors-A Defense Against Microbial Infection in Plants. *Ann. Rev. Plant Physiol.* 35, 243-275.
- N.E. Delfel and J.A. Rothfus. 1977. Antitumor Alkaloids in Callus Cultures of *Cephalotaxus harringtonia*. *Phytochemistry*. 16, 1595-1598.
- J.N. Denis, A. Correa and A.E. Greene. 1991. Direct Highly Efficient Synthesis from S-Dextro Phenylglycine of the Taxol and Taxotere Side Chains. *J. Org. Chem.*, 56, 6939-6942.
- J. Denis, A.E. Greene, D. Guenard and F. Gueritte-Voegelein. 1990. Process for Preparing Taxol. U.S. Patent 4924011.
- J.N. Denis, A.E. Greene, D. Guenard, F. Gueritte-Voegelein, L. Mangatal and P. Potier. 1988. Highly Efficient Practical Approach to Natural Taxol. *J. Am. Chem. Soc.*, 110, 5917-5919.
- J. Ebel. 1984. Induction of Phytoalexin Synthesis in Plants Following Microbial Infection or Treatment with Elicitors. *Bioregulators: Chemistry and Uses*. 257-271.
- U. Eilert. 1987. Elicitation: Methodology and Aspects of Application. In "Cell Culture and Somatic Genetics of Plants," Vol. 4, F. Constabel and I.K. Vasil (eds.) Academic Press, New York, pp. 153-196.
- P.F. Heinsteins. 1985. Future Approaches to the Formation of Secondary Natural Products in Plant Cell Suspension Cultures. *Journal of Natural Products*. 48, 1-9.
- R.A. Holton. 1991. Method for Preparation of Taxol Using an Oxazinone. U.S. Patent 5015744.
- M. Jaziri, B.M. Diallo, M.H. Vanhaelen, R.J. Vanhaelen-Fastre, A. Zhiri, A.G. Becu and J. Homes. 1991. Enzyme-linked Immunosorbent Assay for the Detection and the Semi-Quantitative Determination of Taxane Diterpenoids Related to Taxol in *Taxus* sp. and Tissue Cultures. *J. Pharm. Belg.*, 46, 98-99.

- H. Miyasaka, M. Nasu, T. Yamamoto, Y. Endo and K. Yoneda. 1986. Regulation of Ferruginol and Cryptotanshinone Biosynthesis in Cell Suspension Cultures of *Salvia Miltiorrhiza*. *Phytochemistry*. 25, 637-640.
- G.F. Payne, V. Bringi, C. Prince and M.L. Shuler. 1991. Plant Cell and Tissue Culture in Liquid Systems, Hanser Publishers, Munich.
- R.J. Robins and M.J.C. Rhodes. 1986. The Stimulation of Anthraquinone Production by *Cinchona ledgeriana* Cultures with Polymeric Adsorbents. *Appl. Microbiol. Biotechnol.*, 24, 35-41.
- E.K. Rowinsky, L.A. Cazenave and R.C. Donehower. 1990. Taxol: A Novel Investigational Antimicrotubule Agent. *J. Natl. Cancer Inst.*, 82, 1247-1259.
- M. Seibert and P.G. Kadkade. 1980. Light. In 'Plant Tissue Culture as a Source of Biochemicals'. E.J. Staba (ed), CRC Press, Boca Raton, Florida, pp. 123-141.
- W. van Uden, N. Pras and T.M. Malingre. 1990. The Accumulation of Podophyllotoxin-B-D-glycoside by Cell Suspension Cultures Derived from the Conifer *Callitris drummondii*. *Plant Cell Reports*. 9, 257-260.
- M.C. Wani, H.L. Taylor, M.E. Wall, P. Coggon and M.T. McPhail. 1971. Plant Antitumor Agents. VI. Isolation and Structure of Taxol, a Novel Antileukemic and Antitumor Agent from *Taxus brevifolia*. *J. Am. Chem. Soc.*, 93, 2325-2327.
- P.J. Westgate, A.H. Emery, P.M. Hasegawa and P.F. Heinsteins. 1991. Growth of *Cephalotaxus harringtonia* Plant Cell Cultures. *Appl. Microbial Biotechnol.* 34, 798-803.
- E.R.M. Wickeramesinhe and R.N. Arteca. 1991. Habituated Callus Cultures of *Taxus media* cultivar Hicksii as a Source fo Taxol (Abstract). *Plant Physiol.*, 96, (Supplement) p. 97.
- J.M. Widholm. 1972. The Use of Fluorescein Diacetate and Phenosafranine for Determining Viability of Cultured Plant Cells. *Stain Technol.*, 47, 189-194.
- K.M. Witherup, S.A. Look, M.W. Stasko, T.G. McCloud, H.J. Issaq and G.M. Muschik. 1989. HPLC Separation of Taxol and Related Compounds from *Taxus brevifolia*. *J. Liq. Chrom.*, 12, 2117-2132.
- K.M. Witherup, S.A. Look, M.W. Stasko, T.J. Ghiorzi, G.M. Muschik. 1990. *Taxus* spp. Needles Contain Amounts of Taxol Comparable to the Bark of *Taxus brevifolia*: Analysis and Isolation. *Journal of Natural Products*. 53, 1249-1255.
- L.X. Xu and A.R. Liu. 1991. Determination of Taxol in *Taxus chinensis* by HPLC Method. *Acta Pharmaceutica Sinica*, 26, 537-540.

Table 1.a. List of Elicitors Used in Elicitation of *Taxus* spp. Cell CulturesI. Biotic Elicitors (microorganisms)

- Botrytis cinerea
- Phytophthora megasperma
- Pinellia stripticum
- Oligosporus sp.
- Pythium mamillatum
- Pythium sylvaticum
- Verticillium dahliae
- Verticillium sp.
- Penicillium minioluteum
- Phytophthora lateralis
- Cytospora cincta
- Cytospora leucostoma
- Alternaria brassicicola
- Alternaria solani
- Alternaria cucumerina
- Botrytis squamosa
- Cochliobolus heterostrophus
- Colletotrichum trifolii
- Colletotrichum orbiculum
- Colletotrichum graminicola
- Colletotrichum gloeosporioides
- Cylindrocladium floridanum
- Fusarium crookwellense
- Fusarium heterosporium
- Fusarium oxysporum f. sp. conglutinans
- Fusarium oxysporum f. sp. lycopersici
- Fusarium oxysporum f. sp. pisii
- Gibberella zeae
- Gaeumannomyces graminis var. tritici
- Geotrichum sp.
- Leptosphaeria torrae
- Nectria haematococca MPV1
- Mycosphaerella pinodes
- Ophiostoma ulmi
- Phoma lingam
- Phoma pinodella
- Phytophthora infestans
- Pythium aristosporum
- Pythium graminicola
- Pythium ultimum
- Rhizoctonia solani
- Sclerotinia sp.
- S. nodorum D-45

- Trametes versicolor
- Ustilago maydis
- Venturia inaequalis

Table 1.a. (continued)

## II. Biotic Elicitors (Microbial fractions or products)

- |                       |                |
|-----------------------|----------------|
| • Chitosan            | • Cellulysin   |
| • Lichenan            | • Multifect XL |
| • Glucomannan         | • Multifect CL |
| • Pleuran             | • Resinase     |
| • Glucan              | • Pulpzyme     |
| • Carboxymethylglucan | • SP431        |
| • Hydroxymethylglucan | • Pectinol     |
| • Sulfoethylglucan    | • Rapidase     |
| • Mannan              | • Klerzyme     |
| • Xylan               | • Chitinase    |
| • Mannobiose          |                |
| • Mannotriose         |                |
| • Mannopentose        |                |
| • Mannotetraose       |                |

## III. Abiotic Elicitors (Chemical Stress Agents as well as some naturally occurring biochemicals)

- |  |                      |                     |
|--|----------------------|---------------------|
| • Arachidonic acid                     | • Vanadyl sulfate    | • Fenpropemorph     |
| • Elaidic acid                         | • Uniconazol         | • Prochloraz        |
| • Cyclic AMP                           | • Paclobutrazol      | • Naptifine         |
| • Dibutyl Cyclic AMP                   | • Spermine           | • EDU               |
| • Methyl Jasmon                        | • Spermidine         | • HTA               |
| • Cis - Jasmon                         | • Putrescine         | • MPTA              |
| • Miconazol                            | • Cadavarine         | • Glutathione       |
| • Ferulic acid                         | • Protamine Sulfate  | • EGTA              |
| • AMO-1618                             | • SKF-7997           | • Gibberellins      |
| • Triton X-100                         | • MER 29             | • Absciscic Acid    |
| • Benzoic acid                         | • Ancymidol          | • 1,3-Diphenyl urea |
| • Salicylic acid                       | • Triadimefon        | • Diazolidenyl urea |
| • Propyl gallate                       | • Phosphon D         | • Phloroglucinol    |
| • Sesamol                              | • Thiourea           | • Sodium alginate   |
| • Chlorocholine chloride               | • Dextran Sulfate    | • Carragenan        |
| • 3,4-dichlorophenoxy triethyl (amine) | • Hydroquinone       |                     |
| • Chloroethylphosphonic acid           | • Chitosan glutamate |                     |
| • Diethyldithiocarbamic acid           |                      |                     |
| • Nordihydroguaiaretic acid            |                      |                     |
| • Dithiothreitol                       |                      |                     |
| • Sodium metabisulfite                 |                      |                     |
| • Potassium metabisulfite              |                      |                     |
| • d-amino-DL-Phenylalanine             |                      |                     |

**Table 1.b. List of Precursors, Inhibitors & Stimulants or Activators Used in Regulation of Biosynthesis of Taxol & Taxanes in *T. spp.* cell cultures.**

<u>Precursors</u>	<u>Inhibitors</u>	<u>Stimulants or Activators</u>
Phenylalanine	Chlorocholine chloride	Cyclic AMP
Lysine	Uniconazol	Dibutyl Cyclic AMP
Tyrosine	Paclitaxel	Methyl Jasmone
Tryptophane	SKF-7997	Cis-Jasmone
Methionine	MER 29	Chloroethylphosphonic acid
Tyramine	Ancymidol	Spermine
Sodium acetate	Triadimefon	Spermidine
Potassium acetate	Phosphon D	Putrescine
Ammonium acetate	Fenpropemorph	Cadavarine
Mevalonic acid	Prochloraz	MPTA
Farnesyl acetate	Naptifine	DCPTA
Geranyl acetate	Miconazol	DIPTA
Geranylgeraniol acetate	Silver Nitrate	ACC
Tryptamine	Norbornadiene	HTA
Menthol	AMO 1618	Brassinosteroids
$\alpha$ -Pinene	Alar	BHA
Trans-cinnamic acid	4-amino-5-Hexynoic acid	BHT
Cambrene A	Phenylethanolamine	OTA
Verticillene	Phenethylamine	
Verticillol	Glyphosphate	
Camphor	Dihydrocycloeucaleenol	
Quercetin	Methionine Sulfoxide	
Levulinic acid	8-hydroxyphenethylamine	
Abietic acid	5-Methyl-DL-Tryptophane	
Borneol	$\alpha$ -Fluorophenylalanine	
	5-2 Aminoethyl-L-cysteine hydrochloride	

Table 2: Components (mg/l) of Phyton Catalytic media used for cultivation of *Taxus* cultures.

CHEMICAL INGREDIENT	A	B	C	D	E	F	G	H
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Ammonium Nitrate	134.0	-	33.5	134.0	67.0	400.0	500	400.0
Ammonium Sulfate	3.0	1.5	0.75	3.0	1.5	-	134.0	-
Boric Acid	113.24	-	28.31	113.24	58.62	0.75	6.2	1.5
Calcium Chloride (anhydrous)	-	20.0	50.0	-	-	72.5	113.24	72.5
Calcium Chloride 2H <sub>2</sub> O	-	208.4	-	-	-	-	-	-
Calcium Nitrate 4H <sub>2</sub> O	0.025	-	0.008	0.025	0.0125	388.0	-	388.0
Calcium Nitrate 6H <sub>2</sub> O	0.025	0.01	0.008	0.025	0.0125	-	0.025	0.25
Na <sub>2</sub> EDTA 2H <sub>2</sub> O	37.3	2.5	9.32	37.3	18.65	37.3	37.3	37.3
Ferric Sulfate	-	-	-	-	-	-	-	-
Ferrous Sulfate 7H <sub>2</sub> O	27.8	388.2	8.95	27.8	13.9	-	27.8	27.8
Magnesium Sulfate anhydrous	122.09	23.789	30.5	122.09	61.04	180.7	122.09	180.7
Magnesium Sulfate H <sub>2</sub> O	10.0	0.001	22.5	10.0	5.0	22.3	10.0	22.3
Molybdenum Trioxide	-	-	-	-	-	-	-	-
Molybdic Acid (sodium salt) 2H <sub>2</sub> O	0.25	-	0.062	0.25	0.125	0.25	0.25	0.25
Potassium Chloride	0.75	65.0	-	-	0.375	-	0.75	-
Potassium Iodide	2500.0	80.0	625.0	2500.0	1250.0	-	2500.0	-
Potassium Nitrate	-	-	10.0	-	-	170.0	-	170.0
Potassium Phosphate (monobasic)	-	-	-	-	-	980.0	-	980.0
Potassium Sulfate	-	-	-	-	-	-	-	-
Sodium Phosphate (monobasic anhydrous)	130.5	16.5	32.62	130.5	65.25	-	130.5	-
Sodium Sulfate	200.0	3.0	0.5	2.0	1.0	8.6	-	8.6
Zinc Sulfate 7H <sub>2</sub> O	100.0	100.0	125.0	100.0	50.0	100.0	100.0	100.0
Myo-Inositol	1.0	-	0.75	1.0	0.5	1.0	1.0	1.0
Nicotinic Acid	1.0	-	0.25	1.0	0.5	1.0	1.0	1.0
Pyridoxine HCl	10.0	5.0	3.5	10.0	5.0	10.0	10.0	10.0
Thiamine HCl	282.8	148.4	-	282.8	282.8	1758.8	-	282.8
* Glutamine	-	-	-	-	-	-	-	-
* Tryptophan	-	-	-	-	-	-	-	-
* Phenylalanine	-	-	-	-	-	-	-	-
* Tyrosine	-	30.0	-	-	-	-	-	-
* Methionine	-	20.0	-	-	-	-	-	-
* Sodium Acetate	-	-	-	-	-	-	-	-
Sucrose	10000.0	10.0	10.0	-	-	-	-	-
Ng Benzyladenine	0.002	50000.0	40000.0	10000.0	10000.0	10000.0	20000.0	10000.0
B Naphthalenesuccinic Acid	0.831	2.0	2.0	0.002	0.002	-	-	-
* Ascorbic Acid	50.0	100.0	50.0	100.0	100.0	100.0	1.882	100.0
Picloram	-	-	-	1.2	2.4	1.2	100.0	1.2
Casam Hydrolysate	-	-	500.0	-	-	0.02	1000.0	-
6H 7 DimethylaminolPurine	-	-	-	-	-	-	-	-
Kinadin	-	-	-	-	-	-	-	-
pH	5.8	5.8	5.8	5.8	5.8	5.8	5.8	0.02

\* Filter-sterilized into autoclaved medium

Table 3. Preferred conditions for callus proliferation for various *Taxus* species. The ingredients in the basal media are listed in Table 2.

Species	Basal Medium (Table 2)	Growth Regulators*			
		Type	Auxin Conc (M)	Cytokinin Type	Conc (M)
<i>T. brevifolia</i>	F	P	$5 \times 10^{-6}$	2iP	$10^{-7}$
	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. canadensis</i>	H	P	$5 \times 10^{-6}$	K	$10^{-7}$
	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. chinensis</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
	A	N	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. globosa</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. floridana</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. baccata</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. cuspidata</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. media</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$
<i>T. wallichiana</i>	D	P	$5 \times 10^{-6}$	BA	$10^{-8}$

\*Abbreviations: Picloram (P), Naphthalene acetic acid (N), Benzyladenine (BA), Dimethyl allylamino purine (2iP), Kinetin (K)



Table 4. Typical growth characteristics of *Taxus* sp. suspension cultures

<u>Species</u>	<u>Dry Weight Doubling Time</u>	<u>Fresh Weight Doubling Time</u>	<u>Dry Wt. Density</u>	<u>Fresh Wt. Density</u>
<i>T. brevifolia</i>	2.0 days	3.5 days	20 g/L	400 g/L
<i>T. baccata</i>	2.0	6.0	15	220
<i>T. chinensis</i>	2.5	4.5	20	285
<i>T. canadensis</i>	nd*	8.5	13	260

\*not yet determined

Table 5. Taxol production in various *Taxus* species.

Species	Taxol content (% dry weight)	Medium (See Tables 2&3)	Analysis
<i>T. brevifolia</i>	0.006	F	ELISA
<i>T. canadensis</i>	0.004	H	ELISA
<i>T. baccata</i>	0.0014	D	HPLC
<i>T. globosa</i>	0.0003	G	ELISA
<i>T. cuspidata</i>	0.0025	G	HPLC
<i>T. floridana</i>	0.001	G	ELISA
<i>T. media</i>	0.02	F	ELISA
<i>T. chinensis</i>	0.18	B	HPLC

Table 6. Improvements in productivity due to medium exchange treatment. Numbers are expressed as X-fold improvement over levels achieved in a 15-day batch interval. *Taxus chinensis* cell line K-1 was cultivated in Medium A in the dark.

---

	<u>Total levels*</u>	<u>Extracellular levels</u>
Taxol	4.6	4.89
Total taxanes	4.55	5.94

---

\*Total levels in cells and medium combined

---

Table 7. Effect of Standard GroLux light treatment on taxol and taxane content in 10-day old cultures of *Taxus chinensis* line K-1 cultivated in Medium A. Amounts shown are expressed as  $\mu\text{g}$  extracted from 20 ml of suspension. Cell growth was identical in both treatments (164 mg dry weight per flask).

	Light	Dark
Total taxol: cells and medium:	8.8 $\mu\text{g}$	3.13 $\mu\text{g}$
Extracellular taxol:	76.40%	56.20%
Total taxanes cells and medium:	61.55 $\mu\text{g}$	62.17 $\mu\text{g}$
Extracellular taxanes:	89%	84%

**Table 8.** Comparison of chitosan-glutamate treated to non-elicited suspensions of *Taxus chinensis* line K-1 after 15 day cultivation in medium C. Taxane levels reported are from cells and medium combined. % extra refers to the percentage of extracellular product.

Taxanes	CONTROL			ELICITOR		
	Cell density	10.1 g/L		Cell density	14.2 g/L	
	Cell viability	70-80% viable		Cell viability	75-80% viable	
	% dry wt	mg/L	% Extra	% dry wt	mg/L	% Extra
Taxol	0.054	5.4	72.0	0.098	13.9	85.0
Baccatin III	0.057	5.8	69.9	0.055	7.8	76.6
7-Xylosyl-10-deacetyltaxol	0.040	4.0	63.0	0.048	6.9	77.0
10-deacetyltaxol	0.004	0.4	71.1	0.0	1.0	75.3
Cephalomannine						
10-deacetylbaecatin III						
10-deacetyl-7-epitaxol	0.054	5.4	74.2	0.076	10.8	85.7
7-Epitaxol	0.009	0.9	74.6	0.009	1.3	86.2
Unknown Taxanes	0.203	20.5	79.7	0.240	34.1	90.2
<b>Total Taxanes:</b>	<b>0.421</b>	<b>42.4</b>		<b>0.533</b>	<b>75.8</b>	

**Table 9. Nutrient medium manipulation for enhanced taxane and taxol biosynthesis in *Taxus chinensis* suspension line K-1. 500 mg fresh weight cells were inoculated per 5 mL of medium and incubated in the dark for 18 days. The total taxanes produced (in the cells and medium combined) is reported. The ingredients in media B & C are listed in Table 2.**

<b>Taxane Level</b>	<b>Medium B (mg/L)</b>	<b>Medium C (mg/L)</b>
Baccatin III	4.3	3.9
7-xylosyl 10-deacetyl taxol	8.3	12.9
Cephalomannine	1.1	trace
10-deacetyl 7-epi taxol	4.6	5.4
taxol	24.1	21.3
7-epi taxol	1.3	2.8
other unidentified taxanes*	56.1	63.7
<b>Total taxanes</b>	<b>99.8 mg/l</b>	<b>110 mg/l</b>

**What Is Claimed Is:**

1. A process for recovering taxol and taxanes in high yields from suspension cultures of a *Taxus* species comprising cultivating in a nutrient medium cells derived from callus tissues of a *Taxus* species in suspension cell cultures under cell culture growth and product formation conditions wherein said taxol and taxanes are recovered from said cells and/or said medium of said suspension culture.

2. A process for the efficient initiation and maintenance of callus and suspension cultures of *Taxus* species comprising:

- (a) selecting the appropriate plant parts for callus initiation, and the appropriate callus cell lines for suspension cultures;
- (b) providing efficient sterilization, incubation and transfer procedures for maintaining vigor of explants, calli, and suspensions;
- (c) providing effective anti-browning agents and protocols for continued rapid growth of calli and cell suspension cultures.
- (d) providing effective induction, proliferation and maintenance nutrient media, and appropriate environmental conditions for rapid growth, high cell density, and high cell viability.

3. The method of enhancing total taxol and taxane yields and recoveries in cell cultures comprising:

- (a) cultivating cells derived from callus tissues of a *Taxus* species in cell suspension cultures in one or more nutrient media with different formulations under cell culture growth and product formation conditions to produce taxol and taxanes;

(b) stimulating taxol and taxane biosynthesis, thereby promoting intracellular accumulation and product secretion into the extracellular medium while keeping cells viable for long-term production;

(c) recovering the produced taxol and taxanes from said cells and said medium;

(d) evaluating the level and profile of the produced taxol and taxanes from said cells and said medium; and

(e) selecting the appropriate nutrient medium that exhibits the preferred level and profile of taxol and taxanes.

4. The method of manipulating the production of taxol relative to the amounts of other taxanes, thereby minimizing the production of non-desirable taxanes such as cephalomannine in a cell culture process comprising:

(a) cultivating cells derived from callus tissues of a *Taxus* species in cell suspension cultures in one or more different nutrient media under cell culture growth and product formation conditions;

(b) stimulating taxol and taxane biosynthesis, thereby promoting intracellular accumulation and product secretion into the extracellular medium while keeping cells viable for long-term production;

(c) recovering taxol and other taxanes including any cephalomannine from said cells and said medium;

(d) evaluating the level of taxol and other taxanes including any cephalomannine produced from said cells and said medium; and

(e) selecting the nutrient medium that exhibits preferential production of taxol and concomitant suppression of other undesirable taxanes such as cephalomannine during the production and recovery of taxol and taxanes.



5. The process of any of claims 1-4 wherein said *Taxus* species is selected from the group consisting of *Taxus brevifolia*, *Taxus canadensis*, *Taxus cuspidata*, *Taxus baccata*, *Taxus globosa*, *Taxus floridana*, *Taxus wallichiana*, *Taxus media*, and *Taxus chinensis*.

6. The process of any of claims 1-4 further comprising altering and evaluating environmental conditions for their effects on cell growth and on taxol and taxane production.

7. The process of claim 6 wherein said environmental conditions comprise pH, temperature, light and gaseous components including oxygen, carbon dioxide, and ethylene.

8. The process of claim 1 wherein said cultures are cultivated in continuous or intermittent broadband or narrowband light.

9. The process of claim 1 further comprising periodic nutrient medium exchange.

10. The process of claim 1 further comprising periodic taxol and taxane removal.

11. The process of claim 1 wherein said nutrient media are the same for suspension culture growth and for taxol and taxane production.

12. The process of claim 1 wherein said nutrient media are different for suspension culture growth and for taxol and taxane production.

13. The process of any of claims 11 and 12 wherein growth and product formation are achieved using a one-stage or two-stage batch process, or a fed-batch process, or a semi-continuous process, or a continuous process, or variations thereof.

14. The process of any of claims 1-5 wherein biotic or abiotic elicitors are present in said nutrient media.

15. The process of claim 1 wherein said nutrient media include biosynthetic precursors, metabolic inhibitors and stimulants and/or activators.

16. The process of claim 1 wherein said nutrient media include glutamine or protein hydrolysates.

17. The process of claim 1 wherein said nutrient media include plant hormones selected from the group consisting of indole butyric acid, indole acetic acid, indole-3-acetyl phenylalanine, picloram, dicamba, beta-naphthaleneacetic acid, beta-naphthoxyacetic acid, chlorophenoxyacetic acids, N6-benzyladenine, kinetin, dimethylallylamino-purine, thidiazuron, zeatin, adenine sulfate, and 2-chloro-4-pyridyl-N-Phenyl urea.

18. The process of any of claims 1-4 wherein said taxol and taxanes are recovered from said medium by a mixture of methylene chloride and isopropyl alcohol.

19. The process of claim 18 further comprising purifying said taxol or taxane compounds by use of high performance liquid chromatography.

20. A purified cell culture containing *Taxus chinensis* capable of producing taxol and other taxanes.

21. The process of claim 1 wherein cell cultures of *Taxus* species produce taxol and taxanes in amounts greater than that produced by plant parts, including bark.

22. The process of claim 1 wherein cell cultures of *Taxus chinensis* under specific cultural and environmental conditions produce taxol and taxanes in a shorter time frame and in far higher quantities than cultures of other *Taxus* species.

[received by the International Bureau on 9 August 1993 (09.08.93);  
original claims 7,18,19,21 and 22 cancelled;  
original claims 1-4,11,12,15-17 and 20 amended; new claims 8,10 and 14 added;  
other claims unchanged (5 pages)]

1. A process for recovering taxol and taxanes in high yields from cell cultures of a *Taxus* species comprising:  
cultivating in one or more nutrient media cells derived from callus and/or suspension cultures of a *Taxus* species under growth and product formation conditions wherein said taxol and taxanes are recovered from said cells and/or said medium of said cell culture.

2. A process for the efficient initiation and maintenance of callus and suspension cultures of *Taxus* species comprising:

(a) selecting the appropriate plant parts for callus initiation, and the appropriate callus cell lines for suspension cultures;

(b) providing efficient sterilization, incubation and transfer procedures for maintaining vigor of explants, calli, and suspensions;

(c) providing effective anti-browning agents and protocols for continued rapid growth of calli and cell suspension cultures.

(d) providing effective induction, proliferation and maintenance nutrient media, and appropriate environmental conditions for rapid growth, high cell density, and high cell viability.

3. The method of enhancing total taxol and taxane yields and recoveries in cell cultures comprising:

(a) cultivating cells derived from callus and/or suspension cultures of a *Taxus* species in one or more nutrient media under cell culture growth and product formation conditions to produce taxol and taxanes;

(b) stimulating taxol and taxane biosynthesis, thereby promoting intracellular accumulation and/or product secretion into the extracellular medium;

(c) recovering the produced taxol and taxanes from said cells and/or said medium.

4. The method of manipulating the production of taxol, or another desired taxane, relative to the amounts of other undesired taxanes, in a cell culture process comprising:

(a) cultivating cells derived from callus and/or suspension cultures of a *Taxus* species in one or more nutrient media under cell culture growth and product formation conditions;

(b) stimulating taxol and taxane biosynthesis, thereby promoting intracellular accumulation and product secretion into the extracellular medium;

(c) recovering taxol and other taxanes from said cells and/or said medium;

(d) evaluating the level of taxol and other taxanes produced from said cells and said medium; and

(e) selecting the one or more nutrient medium that exhibits preferential production of taxol or another desired taxane, and concomitant suppression of other undesired taxanes, during the production and recovery of taxol and taxanes.

5. The process of any of claims 1-4 wherein said *Taxus* species is selected from the group consisting of *Taxus brevifolia*, *Taxus canadensis*, *Taxus cuspidata*, *Taxus baccata*, *Taxus globosa*, *Taxus floridana*, *Taxus wallichiana*, *Taxus media*, and *Taxus chinensis*.

6. The process of any of claims 1-4 further comprising altering and evaluating environmental conditions for their effects on cell growth and on taxol and taxane production.

7. The process of any of claims 1-4 wherein said cultures are cultivated in continuous or intermittent broadband or narrowband light.

8. The process of any of claims 1-4 wherein said nutrient media include carbohydrate and/or other carbon sources.

9. The process of any of claims 1-4 wherein said nutrient media include inorganic and/or organic nitrogen sources.

10. The process of any of claims 1-4 wherein said nutrient media include macro and micro salts, rare trace elements, and/or vitamins and other organic supplements.

11. The process of any of claims 1-4 wherein said nutrient media include plant hormones, hormone substitutes and derivatives, and/or synthetic growth regulators.

12. The process of any of claims 1-4 wherein biotic or abiotic elicitors are present in said nutrient media.

13. The process of any of claims 1-4 wherein said nutrient media include biosynthetic precursors, metabolic and nonmetabolic inhibitors, and/or stimulants and/or activators.

14. The process of any of claims 1-4 wherein said nutrient medium contains anti-browning agents, anti-oxidants, stabilizers, enhancers, radical scavengers, and/or reducing agents.

15. The process of any of claims 1-4 wherein said nutrient media are the same for cell culture growth and for taxol and taxane production.

16. The process of any of claims 1-4 wherein said nutrient media are not the same for cell culture growth and for taxol and taxane production.

17. The process of any of claims 1-4 further comprising periodic nutrient medium exchange.

18. The process of any of claims 1-4 further comprising periodic taxol and taxane removal.

19. The process of any of claims 1-4 wherein growth and product formation are achieved using a one-stage or two-stage batch process, or a fed-batch process, or a semi-continuous process, or a continuous process, or variations thereof.

20. A purified cell culture containing *Taxus brevifolia*, *Taxus canadensis*, *Taxus cuspidata*, *Taxus baccata*, *Taxus globosa*, *Taxus floridana*, *Taxus wallichiana*, *Taxus media*, or *Taxus chinensis* capable of producing taxol and taxane in high yields.



## STATEMENT UNDER ARTICLE 19

Claims 1-22 originally were pending in the application.

Originally filed claims 7, 18, 19, 21 and 22 have been cancelled.

Originally filed claims 1, 2, 3, 4, 11, 12, 15, 16, 17, and 20 have been amended.

Originally filed claims 5, 6, 8, 14, 9, 10, and 13 were not amended.

New claims 8, 10, 14, have been added.

The following table indicates the relationship between the originally filed claims and the present amendments to the claims:

Original Claims	Rule 19 Claims	Status
1	1	amended
2	2	amended
3	3	amended
4	4	amended
5	5	not amended
6	6	not amended
7	--	cancelled
8	7	not amended
9	17	not amended
10	18	not amended
11	15	amended
12	16	amended
13	19	amended
14	12	not amended
15	13	amended
16	9	amended
17	11	amended
18	--	cancelled
19	--	cancelled
20	20	amended
21	--	cancelled
22	--	cancelled
	8	new
	10	new
	14	new

The claims were amended to more clearly recite the invention. The new claims are fully supported in the specification and do not constitute new matter. The claims were reordered and renumbered beginning after claim 6.

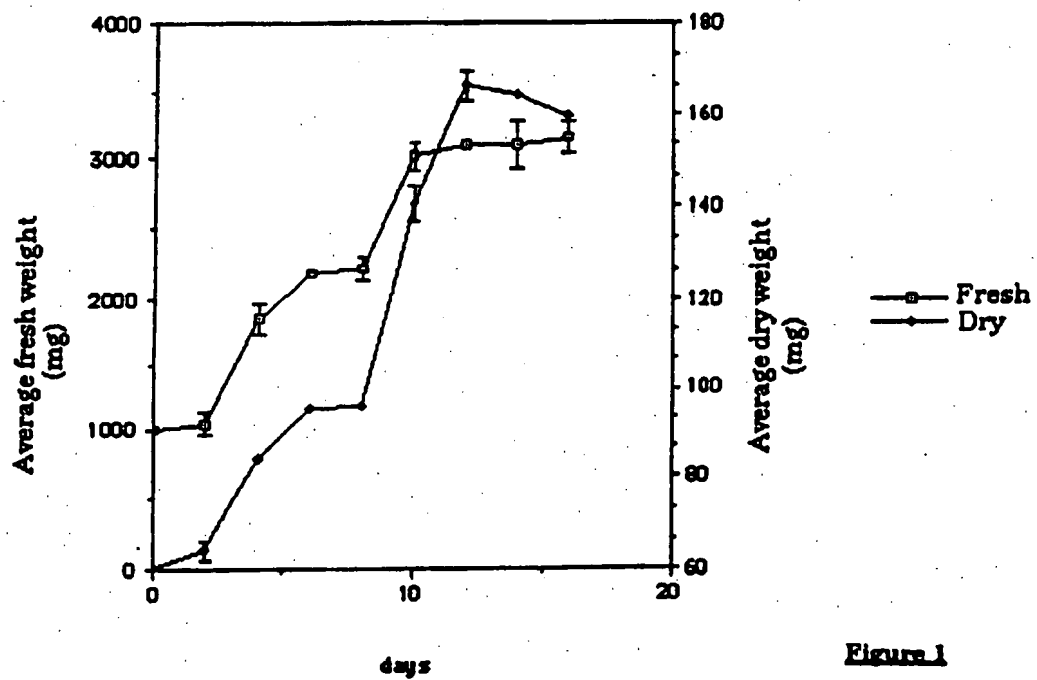


Figure 1

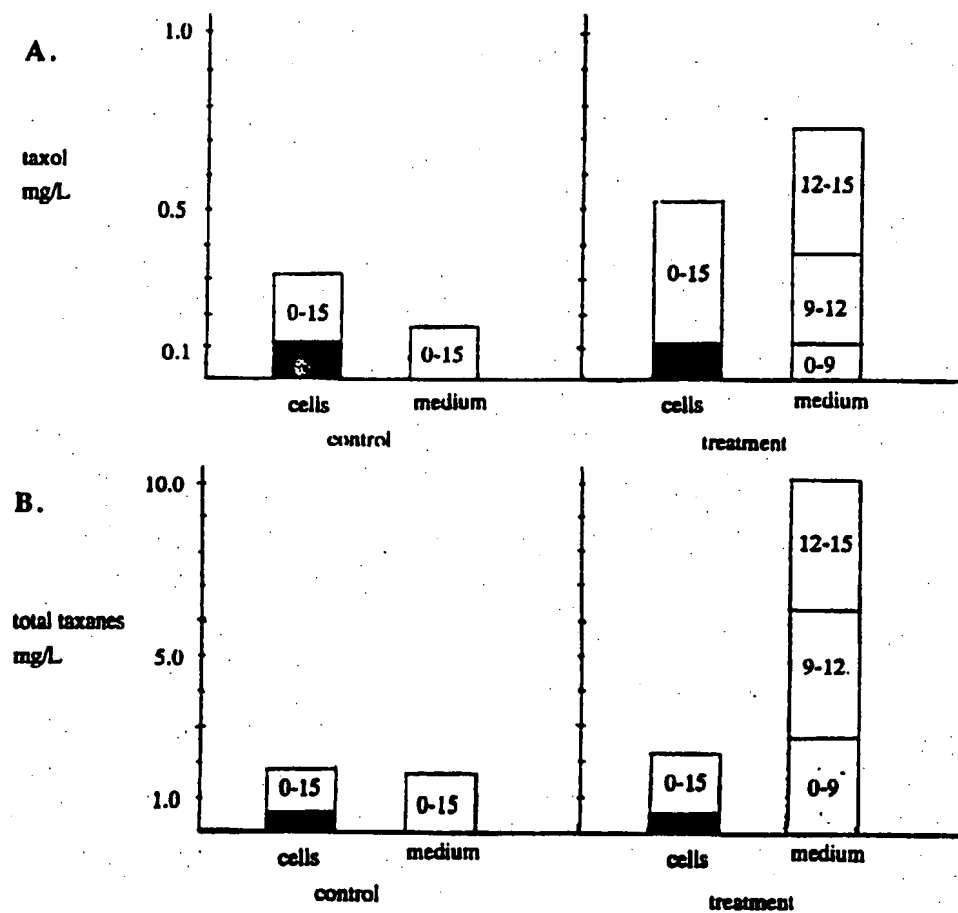


Figure 2.

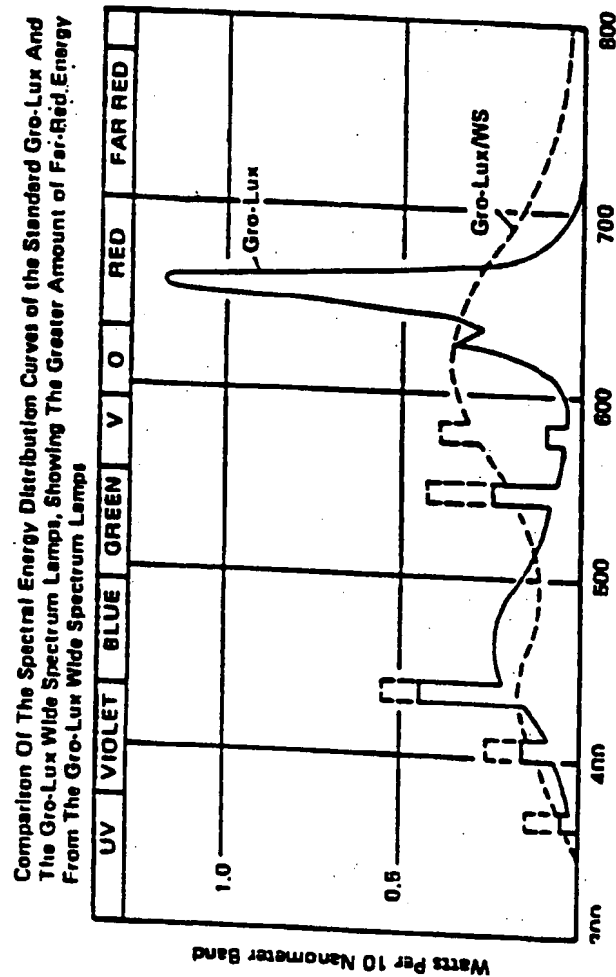


Figure: 3

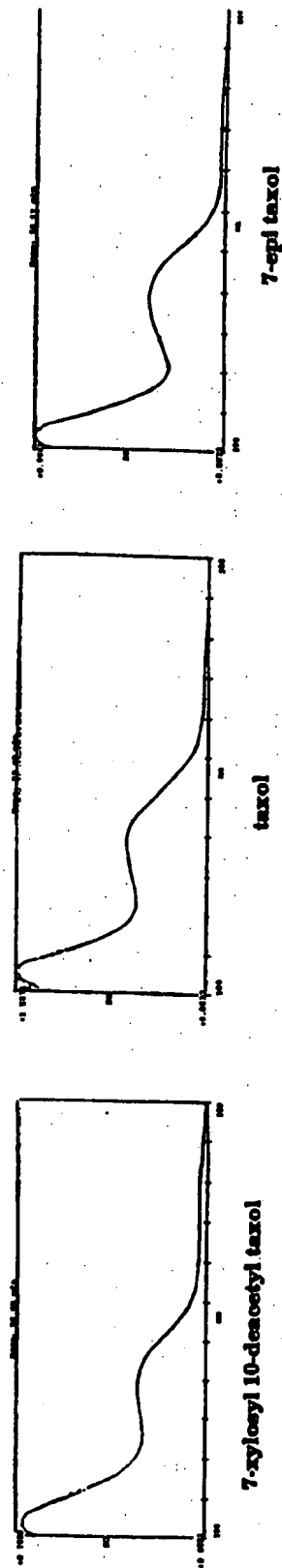
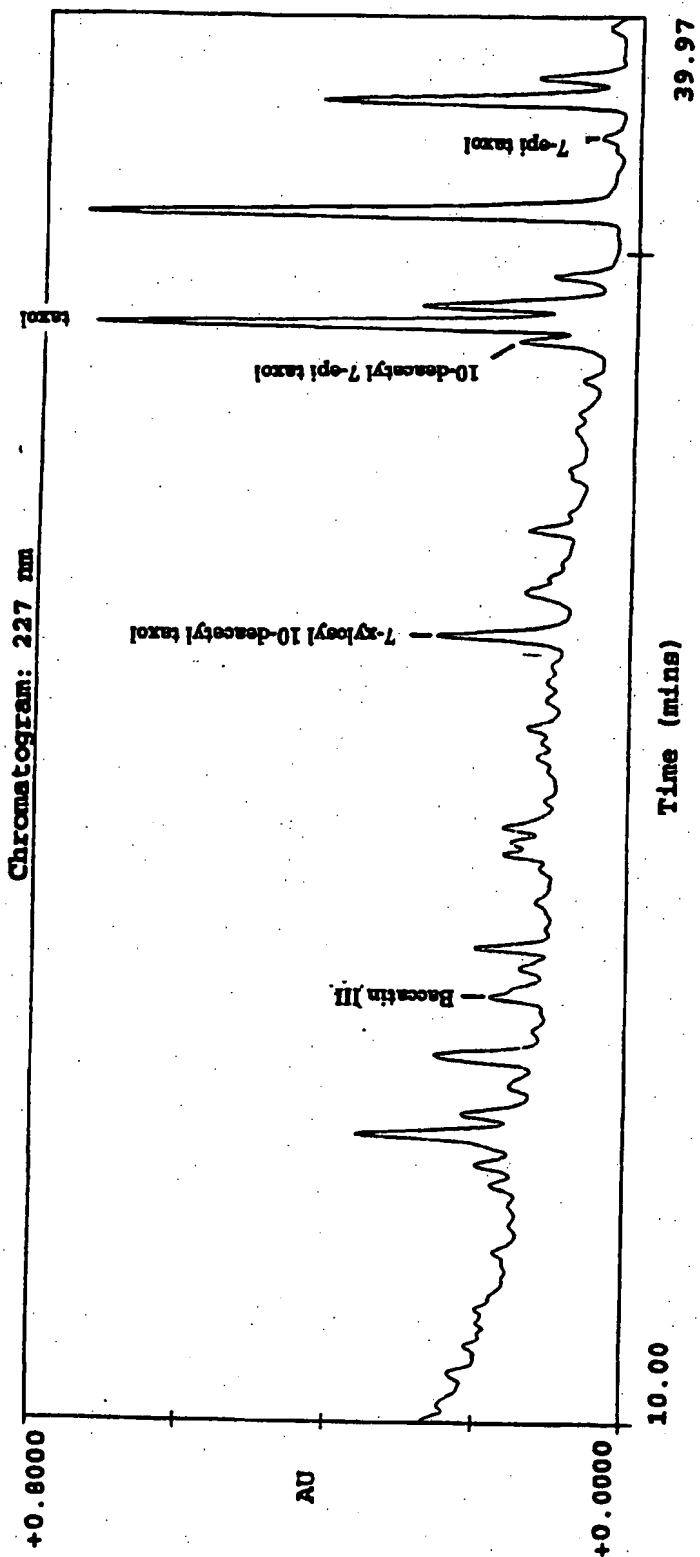


Figure 4

COMPOUND	DAY 25			DAY 42		
	% D. W.	mg/L	% Extracellular	% D. W.	mg/L	% Extracellular
10-Deacetylbaecatin III	0.0000	0.00		0.0000	0.00	
Baecatin III	0.0184	10.43	10.57	0.0420	19.83	14.72
7-Xylosyl-10-deacetylaxol	0.0127	7.19	24.62	0.0283	13.38	45.81
10-deacetylaxol	0.0122	6.95	17.37	0.0127	5.99	0.00
Cephalomannine	0.0000	0.00		0.0119	5.60	86.02
10-deacetyl-7-epitaxol	0.0081	4.61	62.42	0.0275	12.99	72.59
Taxol	0.0427	24.25	70.95	0.3244	153.34	87.52
7-Epitaxol	0.0122	6.92	84.61	0.0154	7.26	85.28
TOTAL - Unknown	0.0452	25.67		0.1625	76.83	
TOTAL Taxanes	0.1515	86.04		0.6245	295.23	

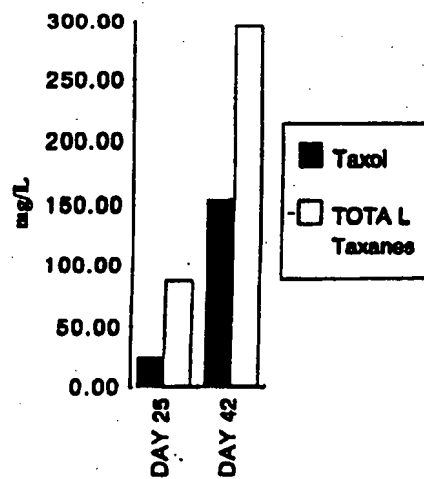


Figure 5.

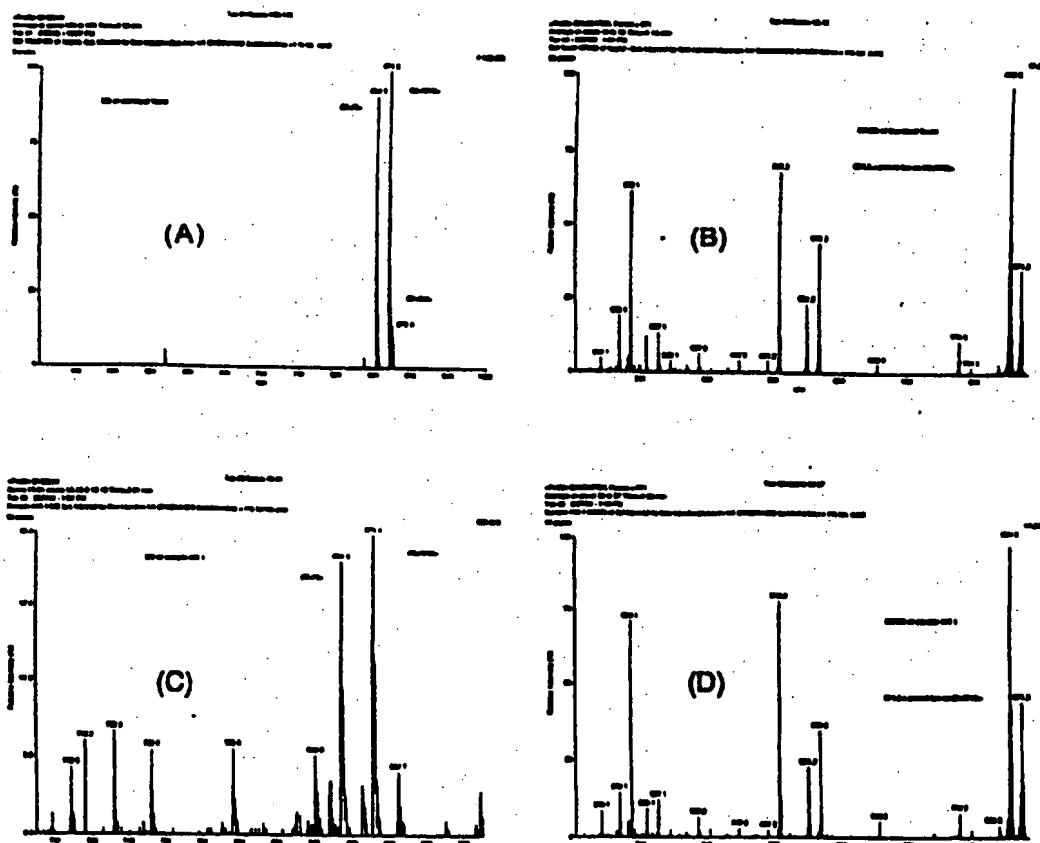


FIGURE 6.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/01576

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : C12P 17/02; C12N 5/00, 5/02, 5/04; C12Q 1/00

US CL : 435/4, 123, 240.25, 240.4, 240.46, 240.48, 244, 245

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/4, 123, 240.25, 240.4, 240.46, 240.48, 244, 245

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
<u>X</u> Y	US, A, 5,019,504 (Christen et al.) 28 May 1991, see entire document.	<u>1-15, 17, 21</u> 18, 19, 22

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	* T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
* A* document defining the general state of the art which is not considered to be part of particular relevance	* X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* E* earlier document published on or after the international filing date	* Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
* L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	* A*	document member of the same patent family
* O* document referring to an oral disclosure, use, exhibition or other means		
* T* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

20 May 1993

Date of mailing of the international search report

08 JUN 1993

Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Authorized officer

DR. HERBERT J. ELLING

Facsimile No. NOT APPLICABLE

Telephone No. (703) 308-0196



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/01576

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Chemical Abstract, 112:3779c Vol. 112, No. 1, 01 January 1990, Xu et al., "Determination of taxol in the extract of <i>Taxus chinensis</i> by reversed phase HPLC" abstract of Yaoxue Xuebao 1989, 24(7) 552-5, see entire abstract.	20
X	Chemical Abstract 116:124148n, Vol. 116, No. 13, 30 March 1992, Xu et al., "Determination of taxol in <i>Taxus chinensis</i> by HPLC method" in Yaoxue Xuebao 1991, 26(7) 537-40, see entire abstract.	18, 20